

**EFFECT OF ACTUATOR DYNAMICS ON CONTROL
OF BEAM FLEXURE DURING NONLINEAR
SLEW OF SCOLE MODEL**

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Simulation of Two Aspects of Physical Limitations on Regulation of Beam Flexure

- One foot travel limitation on displacement of proof-mass actuators
- Time delay of 0.1 second in application of controls

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goal is to assess magnitude of induced errors:
compared to ideal, how much flexure during slew and settling

DISCOS SIMULATION:
 BODIES CONNECTED BY HINGES
 FINITE ELEMENT MODEL OF BEAM PROVIDED BY NASTRAN

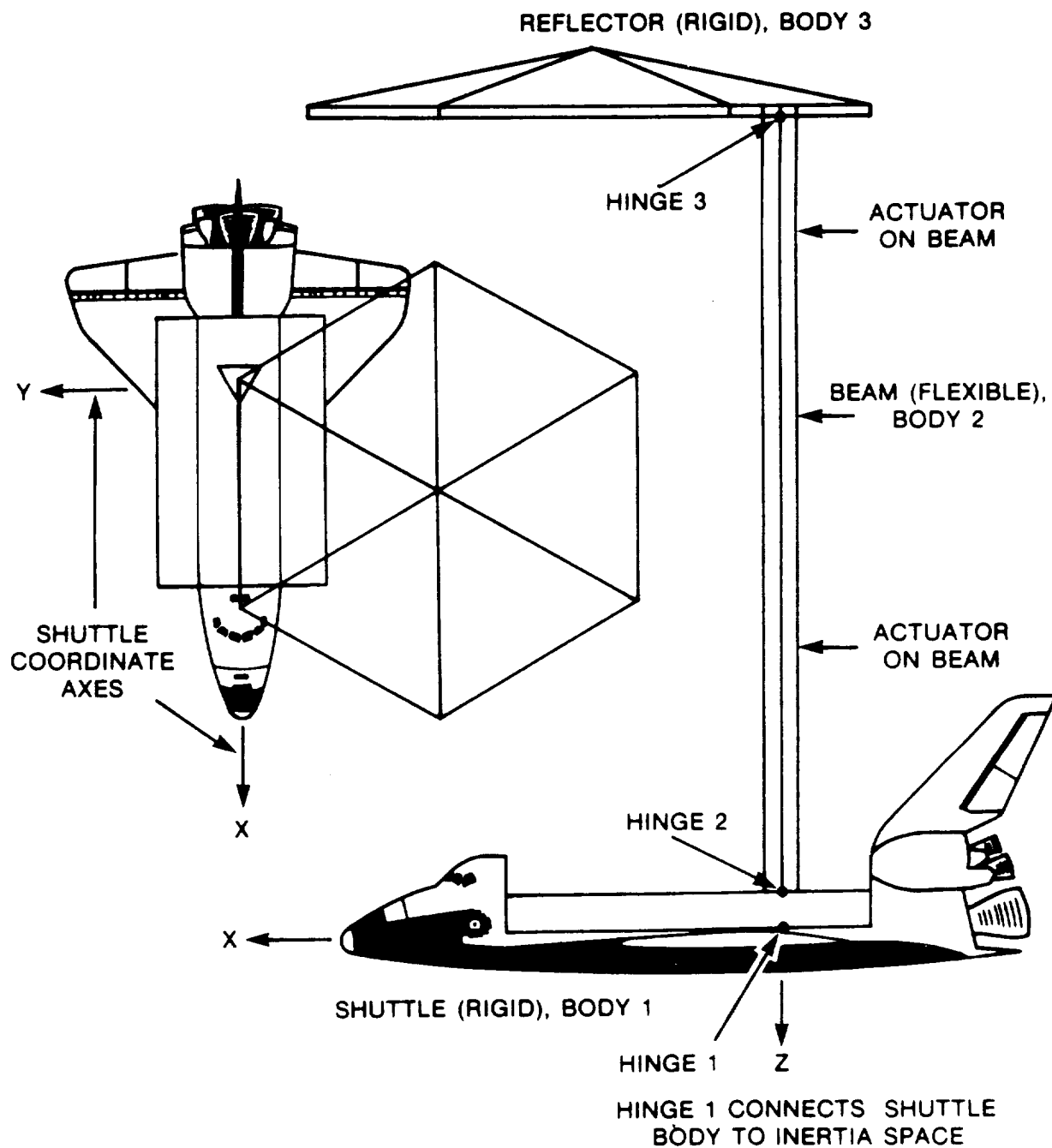


Fig. 1—Scale Configuration

TWO PARTS OF SIMULATION

1. Open-loop commanded slew
10,000 ft-lb thrusters on shuttle body
50 lb force on reflector
bang-bang control law
thrusters on full for 5.65 seconds, then reverse full
slew completed in 11.30 seconds (20^0)
2. Regulation of beam flexure during slew and after (settling)
Linear quadratic regulator (LQR)
vernier thrusters (60 ft-lb torque) on shuttle and reflector
2 sets of 2 axes proof-mass actuators on beam
each set of actuators has 10 lb force in both "x" and "y"
maximum of 1 ft travel distance of proof-mass

PROCEDURES OF THIS ANALYSIS

- NASTRAN finite element model for flexible beam
12 vibration modes of beam
Reflector and shuttle body assumed to be rigid
- Nonlinear DISCOS simulation of 20 degree slew
- Closed-loop linear quadratic regulator (LQR)
- Regulator uses:
 1. Proof mass actuators on beam
Maximum force is 10 lbs.
Maximum stroke is 1 foot.
 2. Thruster moments on shuttle body
Thruster forces on reflector

LQ REGULATOR FOR FLEXIBLE BEAM

- Purpose: To maintain the flexible beam in a nominally unbent position during the large angle slew
- Method: Linear quadratic regulator (LQR) matrices computed offline
- Linearized system equation: $\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t)$
 - $\mathbf{x}(t)$: components are modal amplitudes and rates
 - \mathbf{A} : system matrix
 - \mathbf{B} : control distribution matrix
 - $\mathbf{u}(t)$: input forces, applied at points on the beam
- Cost functional to be minimized:

$$J = \int_0^{\infty} [\mathbf{x}^T(s)\mathbf{Q}\mathbf{x}(s) + \mathbf{u}^T(s)\mathbf{R}\mathbf{u}(s)]ds$$

LQ Regulator (continued)

- Objectives in minimizing cost functional:
 1. Maximize regulator performance
 2. 10 lb limitation on regulator force
- Solve control algebraic Ricatti equation:

$$0 = \mathbf{Q} + \mathbf{A}^T \mathbf{P} + \mathbf{P} \mathbf{A} - \mathbf{P} \mathbf{B} \mathbf{R}^{-1} \mathbf{B}^T \mathbf{P}$$

set $\mathbf{Q} = \mathbf{I}$ and $\mathbf{R} = r\mathbf{I}$, with $r = 10^{-6}$
- Input force vector $\mathbf{u}(t)$ is given by:

$$\mathbf{u}(t) = -\mathbf{R}^{-1} \mathbf{B}^T \mathbf{P} \tilde{\mathbf{x}}(t): \mathbf{u}(t) \text{ is recalculated at each time step}$$

$\tilde{\mathbf{x}}(t)$ incorporates time lag: $\tilde{\mathbf{x}}(t) = \mathbf{x}(t - h)$ with $h = \text{time delay}$

$\tilde{\mathbf{x}}(t)$ can include a reduced set of modes

ASSESS EFFECTS OF 1 FT TRAVEL LIMIT

COMPARISON RUNS : Simulate 20^0 slew, $t = 0$ to 30 seconds

RUN #1	No limit on proof-mass travel distance
RUN #2	1 foot limit imposed
Run #3	No proof-mass actuators

RESULTS

Runs #1 and #2, maximum flexure amplitude is about 0.009^0

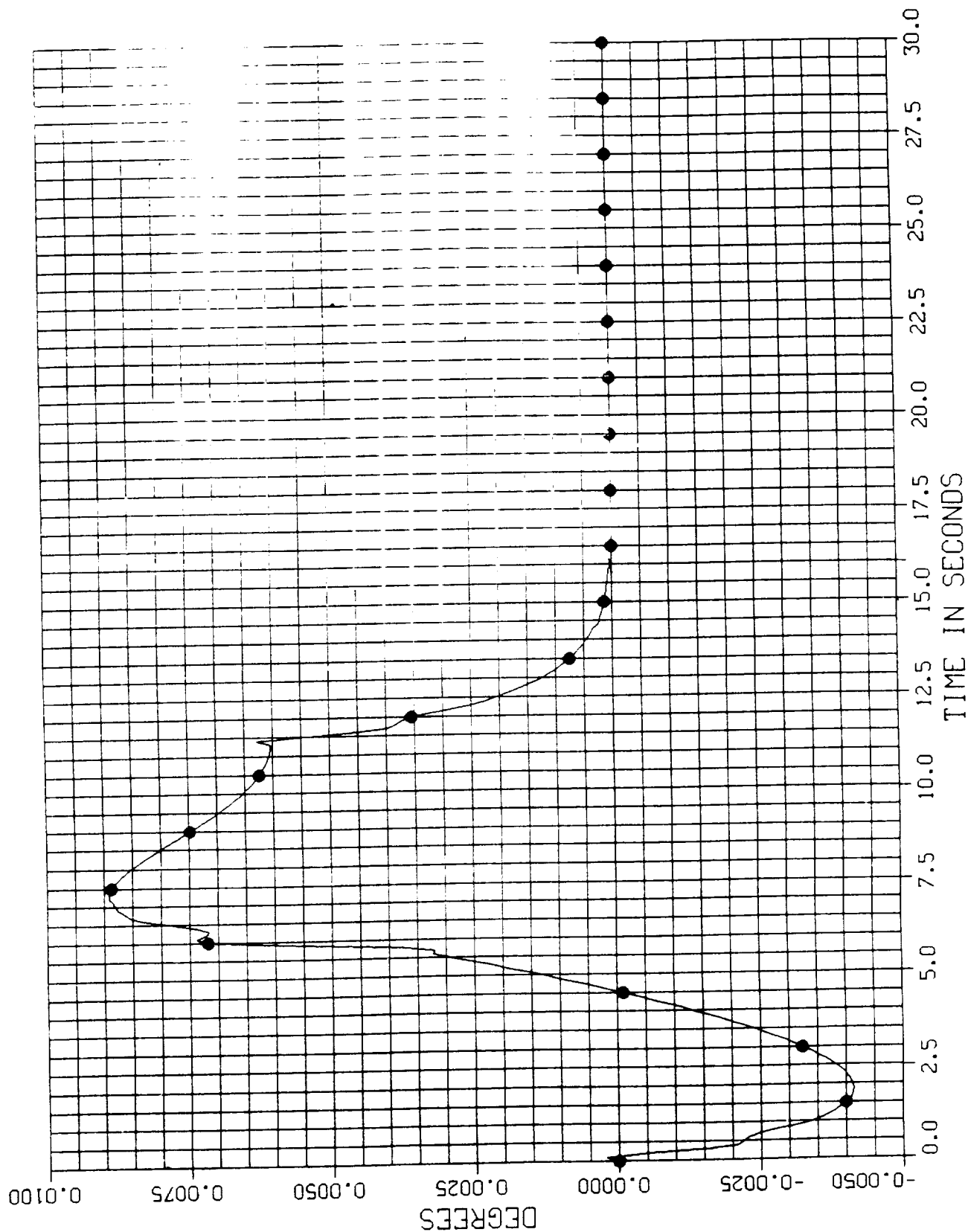
Run #3 maximum flexure is about 0.010^0

Somewhat less damping in run #2 than in run #1

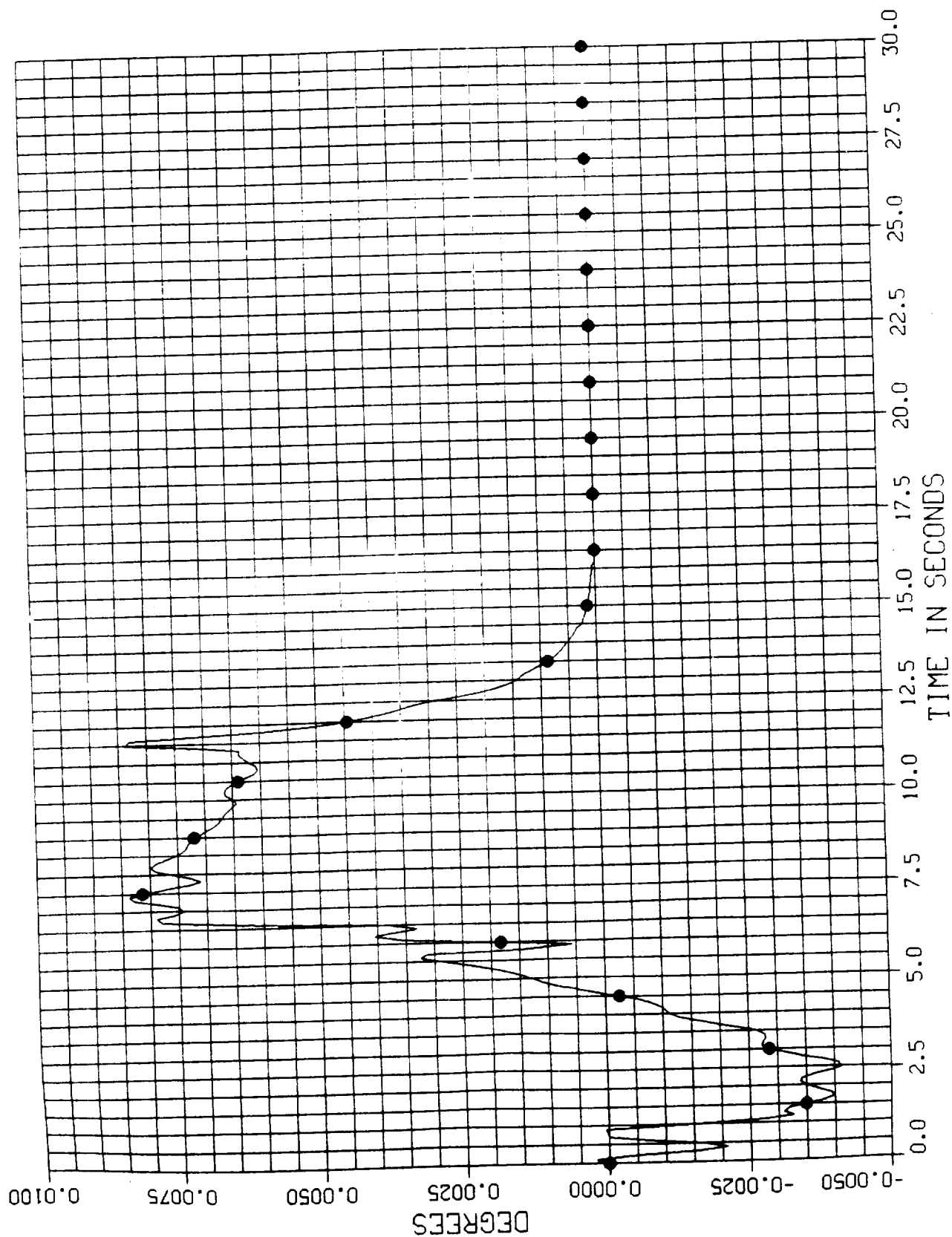
Significantly less damping in run #3 than in the other runs.

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ROLL OF ANTENNA RELATIVE TO SHUTTLE VERSUS TIME

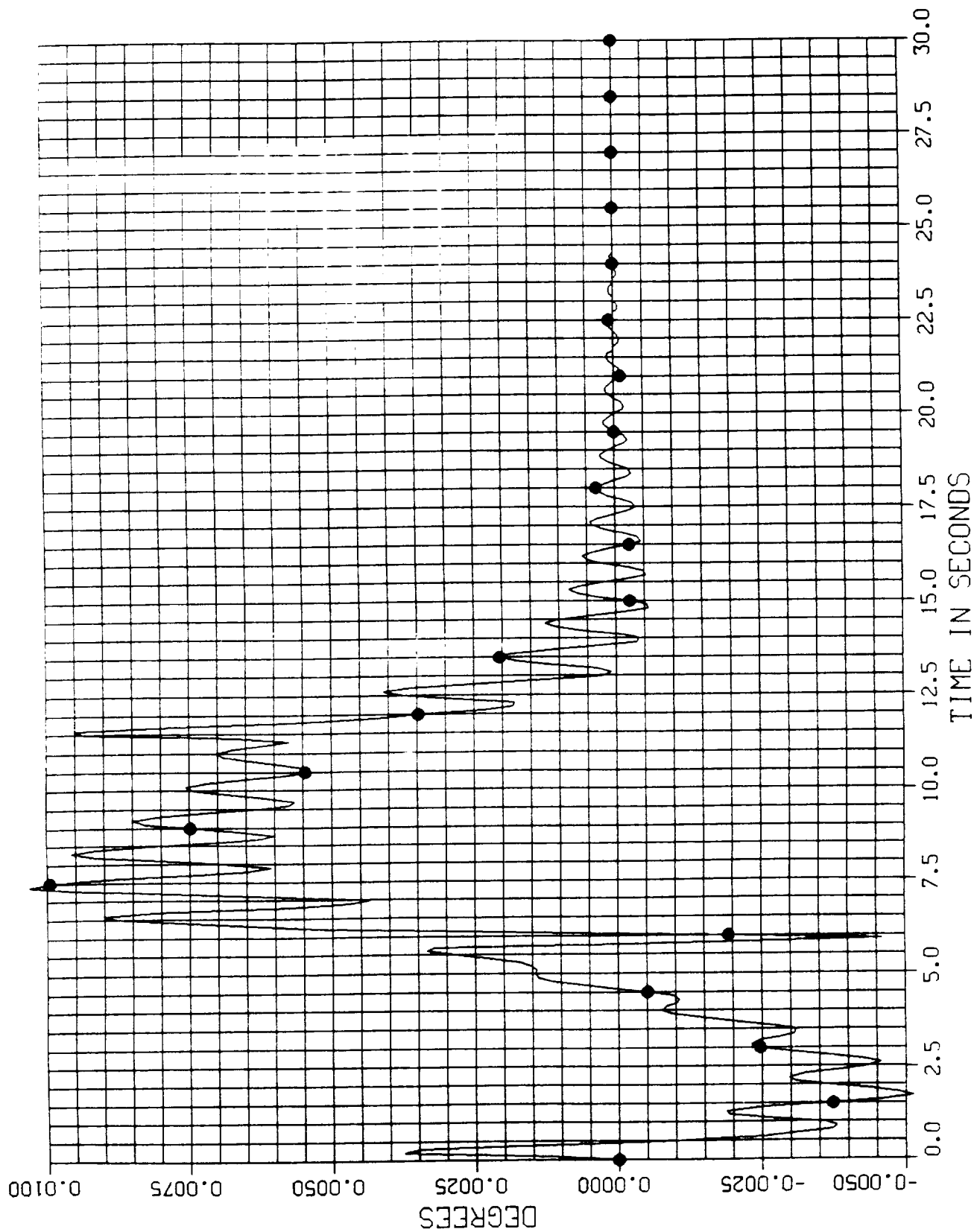


ROLL OF ANTENNA RELATIVE TO SHUTTLE VERSUS TIME



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MODAL CONTROLLABILITY WITH TIME DELAY

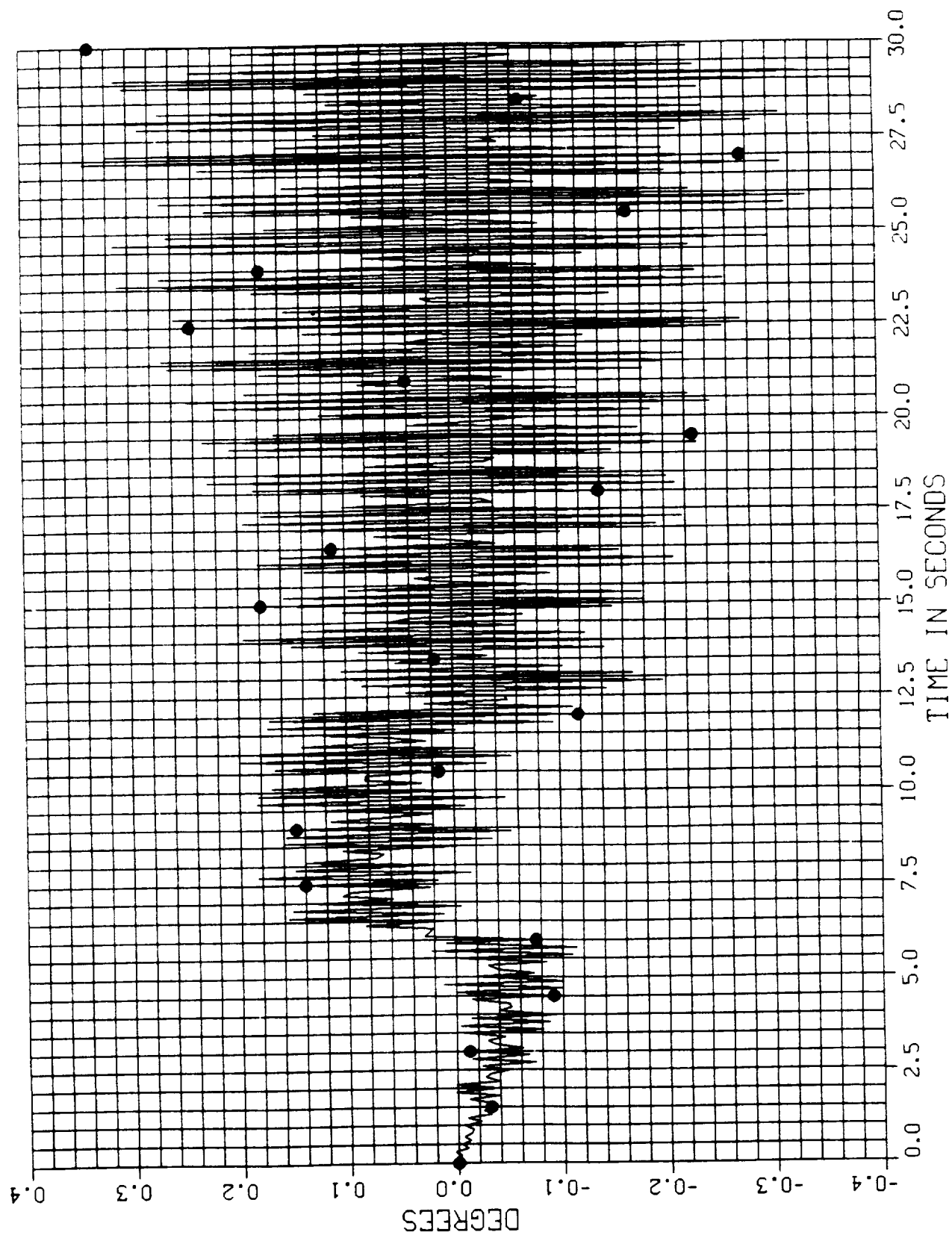
<u>MODE #</u>	<u>ω in radians</u>	<u>τ in seconds</u>	max h <u>$\tau/4$ criterion</u>	max h <u>$\tau/6$ (Reddy & Bainum)</u>
1	1.746	3.60	0.90	0.576
2	1.969	3.195	0.80	0.511
3	5.105	1.232	0.31	0.197
4	7.410	0.848	0.21	<u>0.136</u>
5	12.848	0.489	<u>0.12</u>	0.078
6	29.459	0.213	0.053	0.034
7	34.263	0.183	0.046	0.029
8	74.670	0.084	0.021	0.013
9	78.883	0.080	0.020	0.013
10	106.281	0.059	0.015	0.009
11	142.467	0.044	0.011	0.007
12	145.618	0.043	0.010	0.007

COMPARISON OF CONTROL EFFECTIVENESS

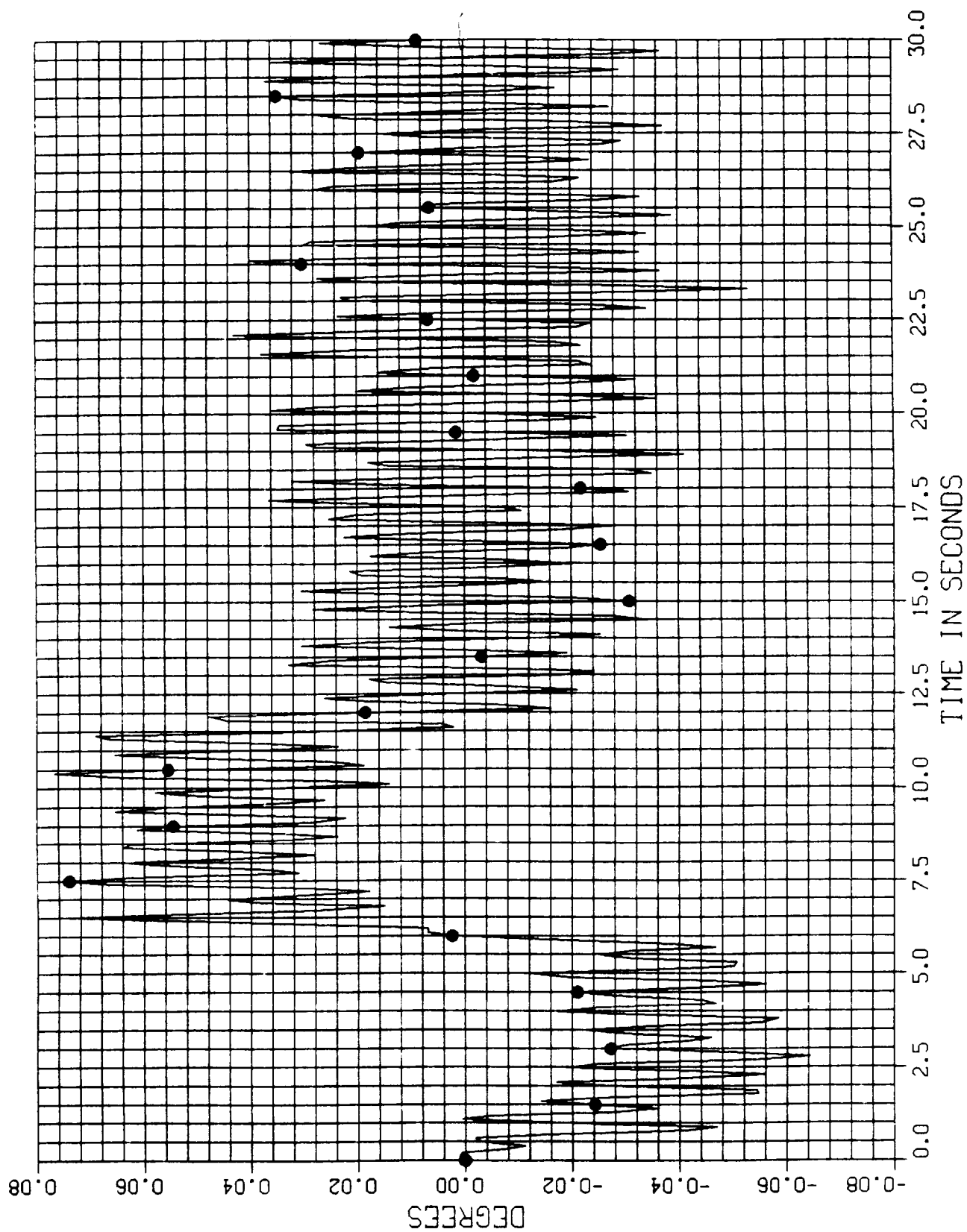
h = .1 sec

	<u>No regulator</u>	<u>No time delay</u>	<u>Modes 1-4</u>	<u>Modes 1-5</u>
Max flexure	0.4 ⁰	0.0085 ⁰	0.08 ⁰	0.115 ⁰
Steady-state	0.4 ⁰	0 at 16 sec	0.036 ⁰	0.05 ⁰

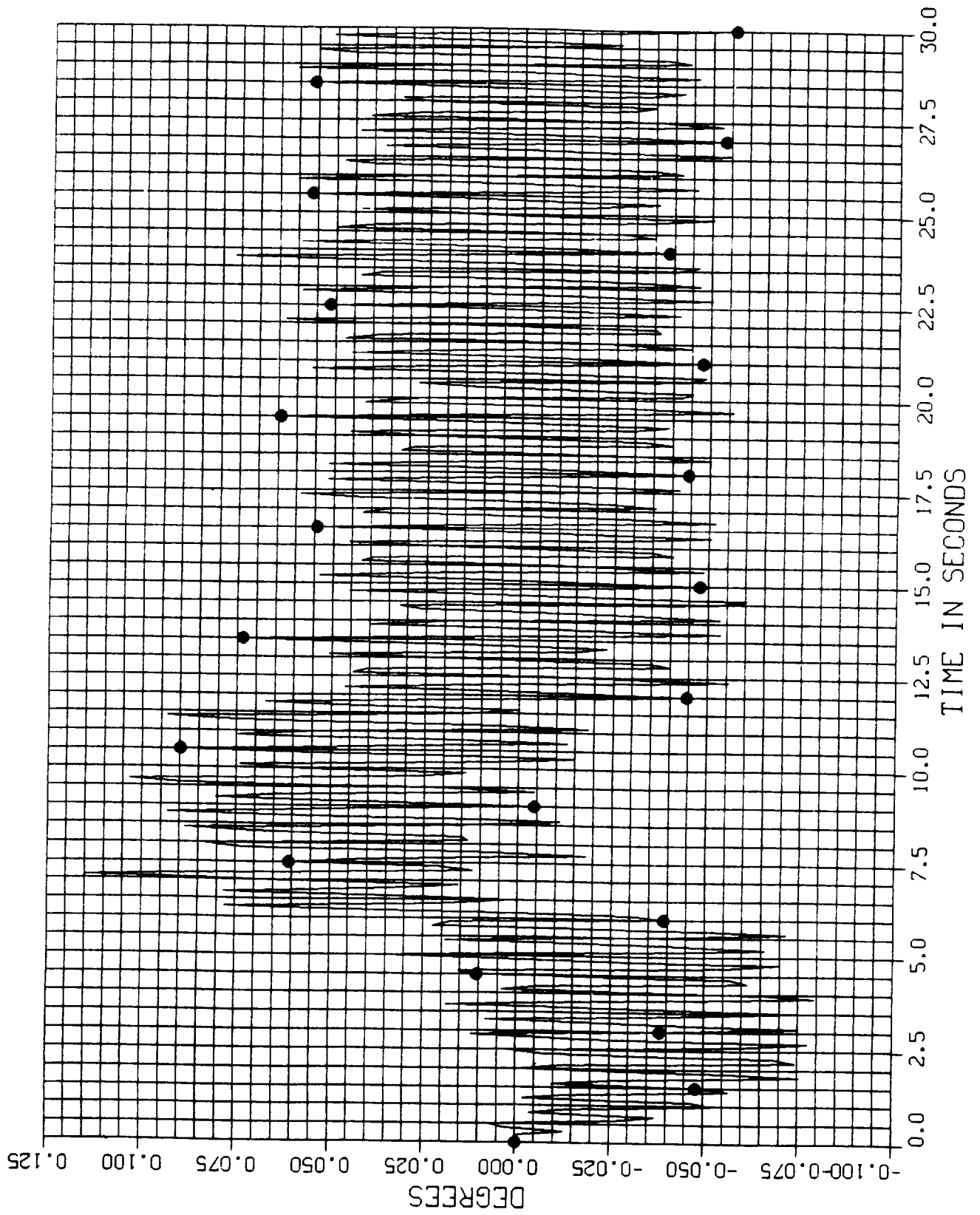
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CONCLUSION

RULE THAT ONLY MODES FOR WHICH

$\text{max period}/6 > h$ (length of time delay)

CAN BE CONTROLLED APPEARS TO HAVE BEEN VALIDATED

AT LEAST FOR LQ REGULATOR of this calculation

NEED MORE ROBUST REGULATOR to do better

